POWER SYSTEMS CALCULATION

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Unkowns are no longer numbers as such, but series with an arbitrary number of coefficients. Multiple ways to embed the equations for the power flow. For example:

$$\sum_{j=1}^{n} Y_{ij} V_j(s) = s \frac{S_i^*}{V_i^*(s)} \quad \text{(Eq. 1)}$$

If we define $X_i(s) = 1/V_i(s)$ and expand the series:

$$\begin{aligned} &Y_{i1}(V_1[0] + sV_1[1] + \dots + s^c V_1[c]) \\ &+\dots+Y_{ii}(V_i[0] + sV_i[1] + \dots + s^c V_i[c]) \\ &+\dots+Y_{in}(V_n[0] + sV_n[1] + \dots + s^c V_n[c]) = sS_i^*(X_i[0] + sX_i[1] + \dots + s^{c-1} X_i[c-1]) \end{aligned} \quad \text{(Eq. 2)}$$

This way we get to a linear system with a constant matrix. The coefficients to compute only depend on past terms!

Overview

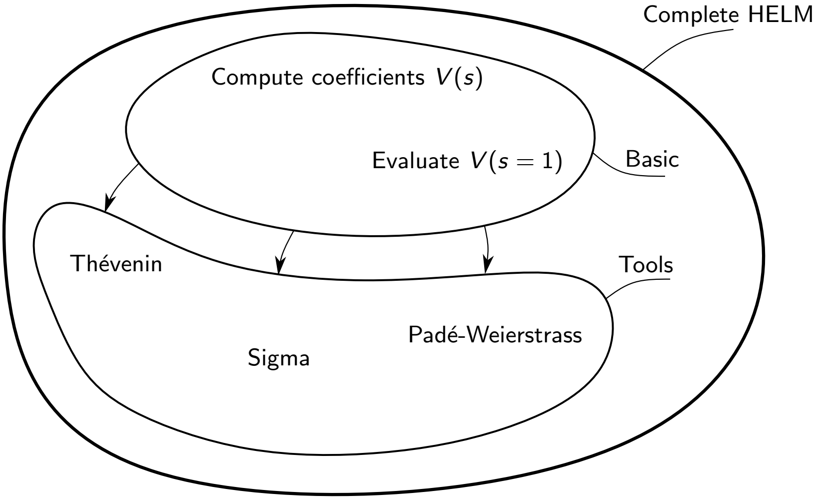

Figure 1. Perspective of the HELM. Basic reffers to obtaining the final solution whereas the tools complement the results.

- Sigma plot of the IEEE30 system when active power changes.
- Sigma plot of the IEEE30 system when reactive power changes.

GridCal

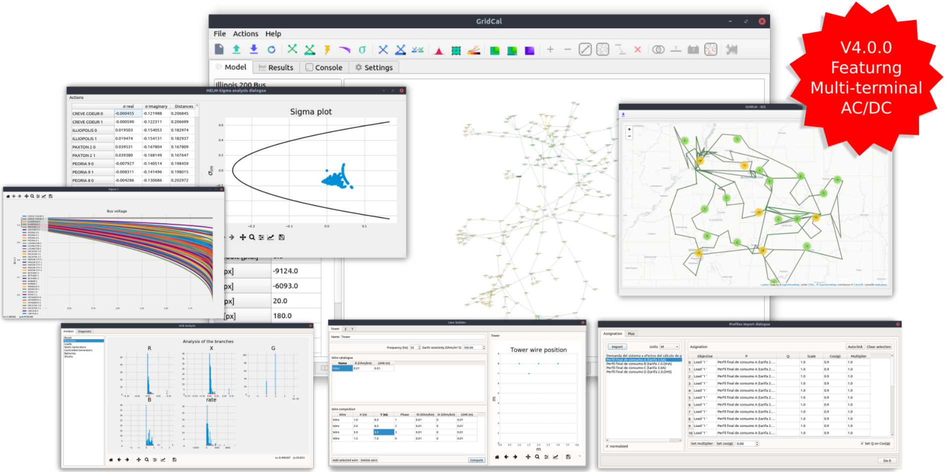

Figure 2. General view of GridCal with its GUI

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Modelling

We are interested in a generic model for power lines, transformers and converters.

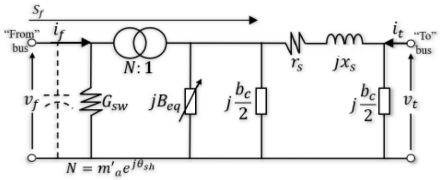

Figure 3. Flexible General Branch Model to model any element. Reference: Bustos, A. A. and Kazemtabrizi, B. (2018) 'Flexible general branch model unified power flow algorithm for future flexible AC/DC networks.' in 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Euroope (EEEIC / ICPS Europe): 12-15 June 2018, Palermo, Italy. Conference proceedings. Piscataway, NJ: IEEE.

Variable	Control
θ_{sh}	θ_{sh}
θ_{sh}	P_f
m_a	v_t
m_a	Q_t
B_{eq}	v_{dc}
B_{eq}	Zero Q constraint

Mode	Constraint 1	Constraint 2	VSC control
1	θ_{sh}	v_{ac}	I
2	P_f	Q_{ac}	I
3	P_f	v_{ac}	I
4	v_{dc}	Q_{ac}	II
5	v_{dc}	v_{ac}	II
6	v_{dc} droop	Q_{ac}	III
7	v_{dc} droop	v_{ac}	III

Table 1. VSC control models and relationship between the variables and the controlled magnitude

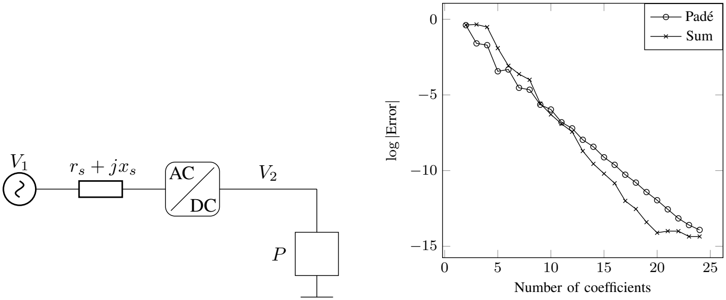

Figure 4. Left: simple system with a VSC converter. Right: maximum error depending on the number of coefficients in the series.

One embedded equation becomes for instance:

$$I_f(s) = y_s V_2(s) - y_s V_1(s) + sj\frac{b_c}{2} V_2(s) + sjB_{eq} V_2(s) + sG I_f^{re}(s) I_f^{re}(s) I_f^{im}(s) I_f^{im}(s) V_2(s) \quad \text{(Eq. 1)}$$

HELM is also suitable to solve rather complicated equations like this one.

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Formulation

We define the problem in two steps.

- Admittances side:

$$\begin{cases} I^{l+\frac{1}{2}} - I^{l} = \alpha(V^{l+\frac{1}{2}} - V^{l}), \\ YV^{l+\frac{1}{2}} = I_0 + I^{l+\frac{1}{2}}. \end{cases} \quad \text{(Eq. 1)}$$

- Load/generator side:

$$\begin{cases} I^{l+1} - I^{l+\frac{1}{2}} = \beta(V^{l+1} - V^{l+\frac{1}{2}}), \\ (V^{l+1})^{*} I^{l+1} = S^{*}. \end{cases} \quad \text{(Eq. 2)}$$

Matrices α and β can be arbitrarily defined, but for instance:

$$\begin{cases} \alpha = \text{diag}(S^{*}/|V|^{2}), \\ \beta = \text{diag}(Y + \alpha). \end{cases} \quad \text{(Eq. 3)}$$

These are constant matrices. Contrary to the typical NR, there are no inverses as such (expensive computation with $\mathcal{O}(n^3)$).

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Multidimensional power flow

- Dimensions: position (nodes), changes in power, time...
- Voltages expressed in the separated form: $V(x, q, t) = \sum_{m=1}^{M} V_m \otimes Q_m \otimes T_m$.

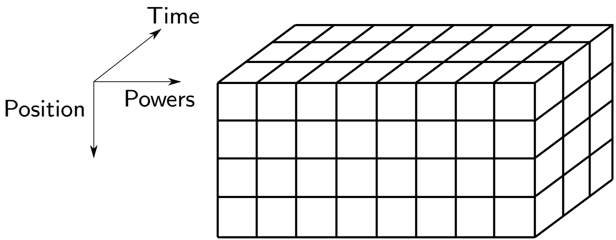

Figure 5. Representation of the cube of solutions

- Need to compute $M(n_{\text{buses}} + n_{\text{powers}} + n_{\text{time}})$ instead of $n_{\text{buses}} \cdot n_{\text{powers}} \cdot n_{\text{time}}$ unknowns.
- Can it be adapted for changes in the topology so that we can employ it for contingency analysis ($N-1$, $N-2$...)?

Algorithm

The outer loop follows the ASD procedure while the inner one is based on the alternating directions technique.

Algorithm 1 Pseudocode for the PGD combined with ASD

for $\gamma = 1$ to N_γ **do**
    Compute power side of the problem with PGD: $I = S^* \oslash V^{*[\gamma]}$
    for $m = 1$ to M **do**
        Define $I = \sum_{m=1}^{M-1} I_m \otimes Q_m \otimes T_m + I_M \otimes Q_M \otimes T_M$
        for $k = 1$ to N_k **do**
            Compute $I_M^{[k+1]}$ with $Q_M^{[k]}$ and $T_M^{[k]}$.
            Compute $Q_M^{[k+1]}$ with $I_M^{[k+1]}$ and $T_M^{[k]}$.
            Compute $T_M^{[k+1]}$ with $I_M^{[k+1]}$ and $Q_M^{[k+1]}$.
        end for
    end for
    Compute admittances side of the problem directly: $V^{[\gamma+1]} = Y^{-1}(I + I_0)$.
end for

- Show code and results.

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